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Scientific Support of Construction of Unique Buildings and Structures and Facilities of Increased Danger

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Abstract. A range of works on scientific support for the construction of unique buildings and the structures and facilities of increased danger, such as airport facilities, long-span and high-rise buildings is being implemented at the department "Computer Aided Design in Civil Engineering" of Ural Federal University. The scope of work includes: numerical simulation of wind and snow loads, analysis of progressive collapse and seismic impacts, verification of design solutions. The results of wind, snow loads and progressive collapse of airport buildings in the cities of Orenburg, Rostov-on-Don and Perm are considered in the article.Introduction

Modern requirements for the design of unique construction objects and facilities with an increased level of danger include the modeling of wind and snow impacts on buildings and structures, as well as their calculation for possible progressive destruction. Information on the distribution of wind and snow loads on buildings and structures of complex configuration can be obtained with the help of computer simulation methods, which is a necessary addition to the information obtained in studies in wind tunnels, the cost of which is quite high. Analysis for the progressive destruction is necessary because of the ever increasing number of accidents in natural and technogenic disasters and terrorist attacks.

1. Numerical simulation for the analysis of wind and snow loads

Numerical simulation for determination of wind loads and analysis of the magnitude of snow loads was performed for the following objects:

- Hangar for airplanes, Orenburg airport facilities;
- VIP-terminal, "Yuzhny" airport facilities, Rostov-on-Don;
- Fuel-filling complex, airport "Yuzhny" facilities, Rostov-on-Don.

A numerical model of an incompressible air flow was used on the basis of the Reynolds equations. The equation of motion of the pulse:

$$\rho\frac{dV}{dt} = -grad(p + \frac{2}{3}\mu_\Sigma divV() + 2Div(\mu_\Sigma \dot{S}) \quad (1)$$

where: ρ-density, v-speed, p-pressure, $\mu_\Sigma = \mu + \mu_t$, μ-coefficient of molecular viscosity, μ_t- coefficient of turbulent viscosity, $\dot{S}$ -velocity tensor.

Equation of continuity:

$$div(V) = 0 \tag{2}$$

Numerical simulation is performed using finite element method applied in the software package ANSYS.

To solve differential equations, the finite volume method is used. A "hybrid" turbulence model SST (shear stress transfer) is used. The model effectively combines the stability and accuracy of the standard k - ω model in the near-wall regions, and the efficiency of the k - ε model at a distance from the walls with a smooth transition between them (the introduction of a docking function) [1-15].

The computational model is the numerical analogue of wind tunnel. The simulated objects and surrounding objects are placed in the domain, whose sizes are selected so that air flow on its boundaries is not affected by the buildings placed in it. The size of the computational domain in vertical, lateral and longitudinal flow directions is defined by the simulated site development and boundary conditions. In the experience of testing in wind tunnels the building height H is assumed to affect up to a distance of 10 H. This height can be recommended to be an essential requirement to the model. According to test calculations made by the Institute of Architecture AIJ, Japan [2], the size in the vertical flow direction for an isolated building should be not less than 5H.

In the computational domain, for each geometry of the simulated buildings on the surface of the earth, hexahedral meshes with pressed boundary layers near solid boundaries are constructed. On the boundaries of the computational domain, the "Inlet" boundary conditions are used (the wind flow can only enter the domain), "Opening" (the flow at the boundary can be directed both inside and out of the domain), "Wall" (on the surface of the building and the land).

For the Inlet input area, a power law of wind speed variation is given, corresponding to the experimental data on wind propagation in the surface layer of the atmosphere. As a rule, it is enough to consider eight different directions of wind action, although this depends on the shape of the building itself and the shape of the surrounding objects included in the domain. When changing the direction of the wind flow, the building model rotates by the corresponding angle. Thus, the design model is an analog of the wind tunnel. Figure 1 shows the facades of the aircraft hangar and the computational domain. Figure 2 is a schematic diagram of wind directions.

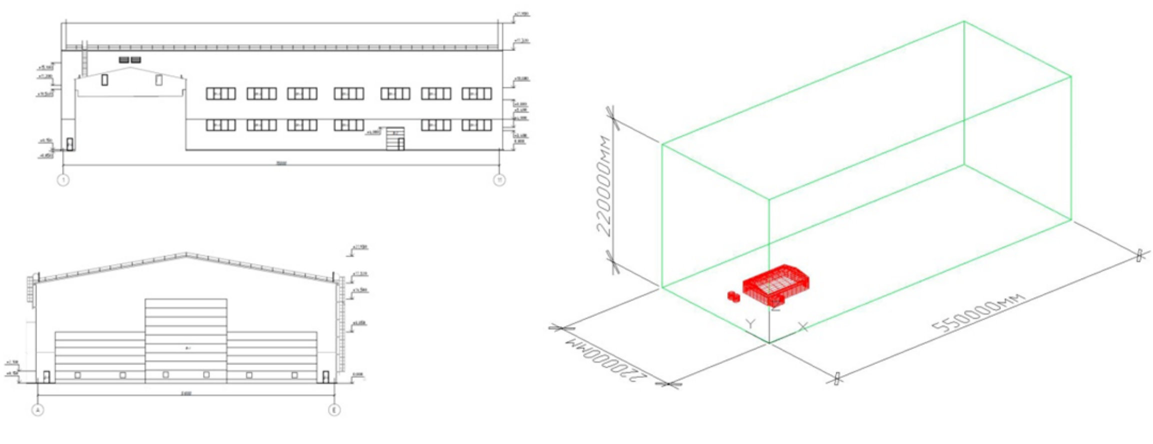

Figure 1. Hangar for aircraft placement and the domain configuration.

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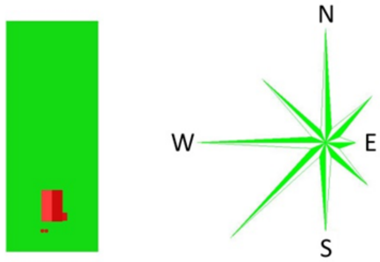

Figure 2. Schematic diagram of wind directions**.**

Figure 3 shows the typical picture of the distribution of wind velocities around the hangar in the north-west wind direction.

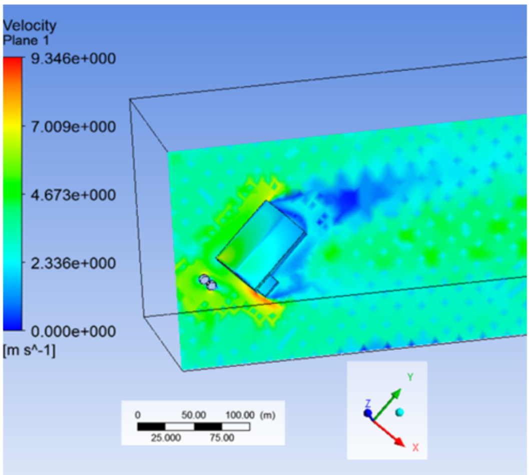

Figure 3. Wind velocity around the hangar in the north-west wind direction.

The distribution of wind velocities makes it possible to determine the pressure on the surface of the building. A quantitative analysis of the results shows that the values of wind loads do not exceed the normative design ones. Figure 4 schematically shows the wind direction diagram (on the left) and the domain size (on the right) for two variants of the configuration of VIP terminal building of “Yuzhny” airport complex (Rostov-on-Don).

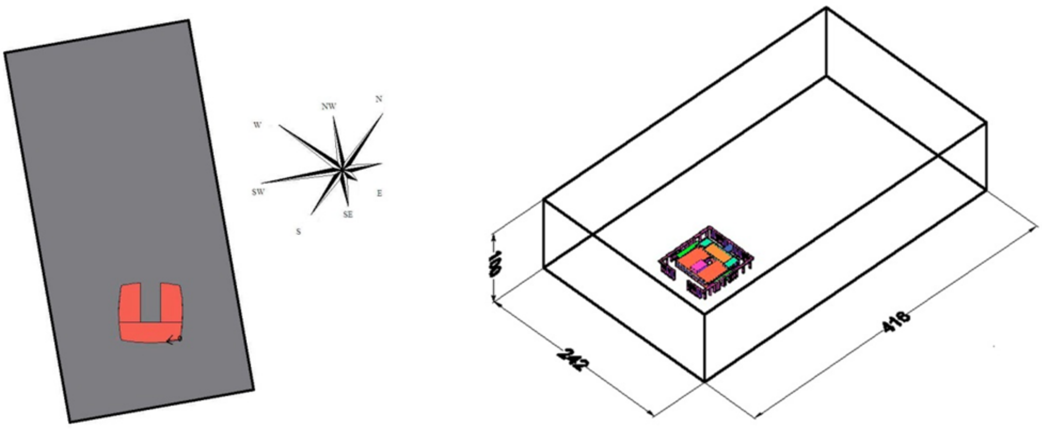

Figure 4. Wind direction diagram and the domain size.

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Figure 5 shows a typical picture of wind velocities for the building without a colonnade, and with a colonnade and a slightly modified roof geometry for the south-west wind direction.

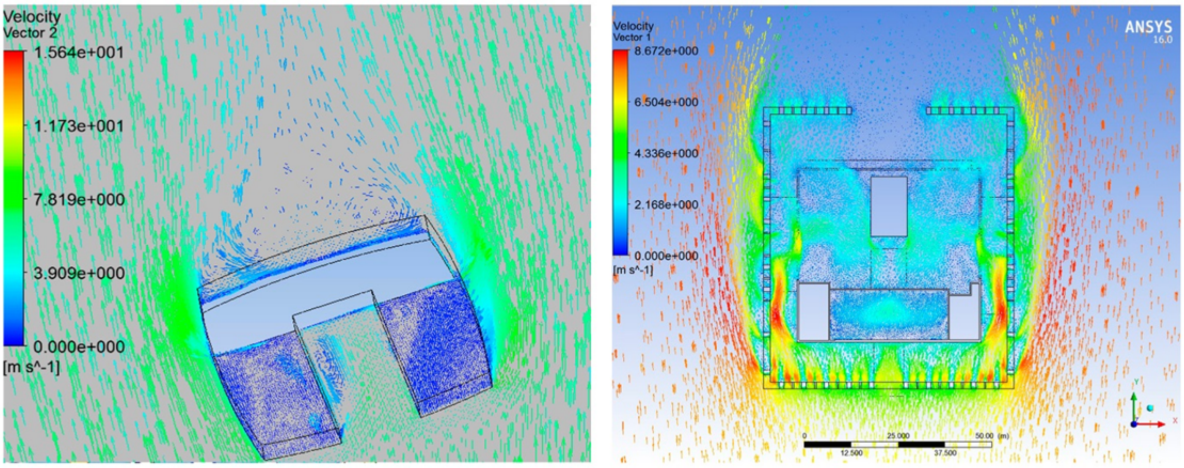

Figure 5. A typical picture of wind speeds for two variants of building configuration.

An analysis of results showed that the values of wind loads do not exceed ones adopted in the design. The evaluation of the snow loads taken in the project was carried out. It has been shown that the loads correspond to normative data. Based on the results of verification calculations, recommendations are given for determining the aerodynamic coefficients for facilities with an increased level of responsibility for the Fuel and Filling Complex "Yuzhny" of the international airport "Yuzhny".

2. The analysis for the progressive collapse

The analysis for the progressive collapse of the building "New air terminal complex of domestic and International air lines of the International airport "Bolshoe Savino", Perm was performed. The analysis carried out in a non-linear setting in the LIRA program with the use of special finite elements in the model of the building - KE210 (columns, beams), KE240, KE241, KE244 (plates, walls). Analysis has been made for the normative dead and long-term live loads of the winter operation period, taking into account the responsibility coefficient 1.2. The finite element model of the building is shown in Figures 6-8.

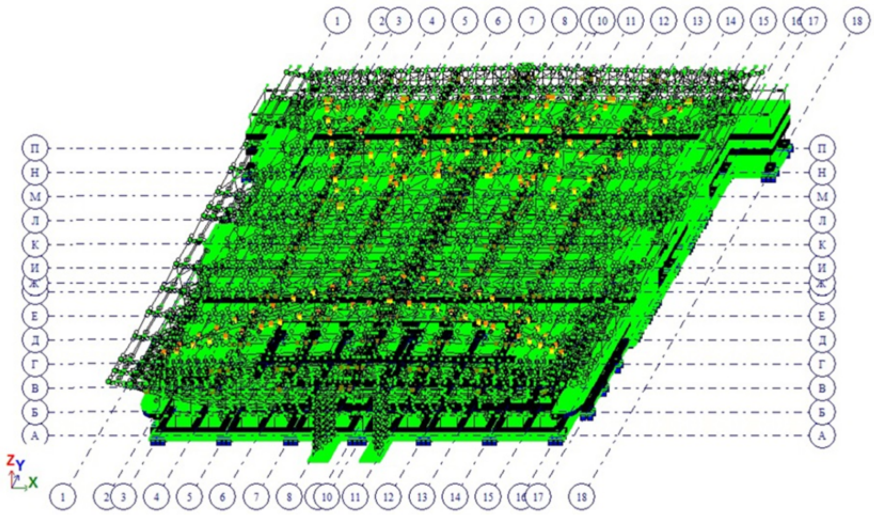

Figure 6. The finite element model.

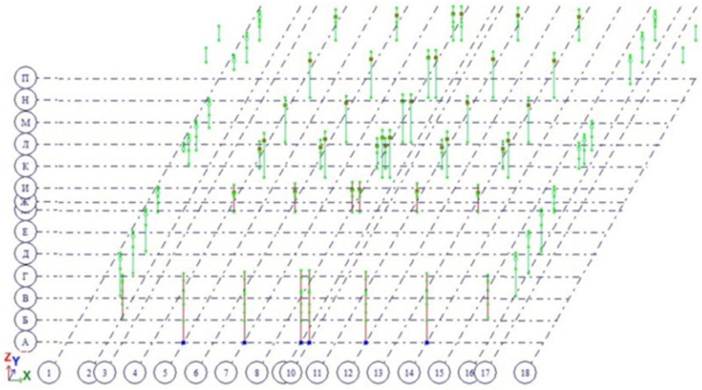

Figure 7. Arrangement of reinforced concrete columns.

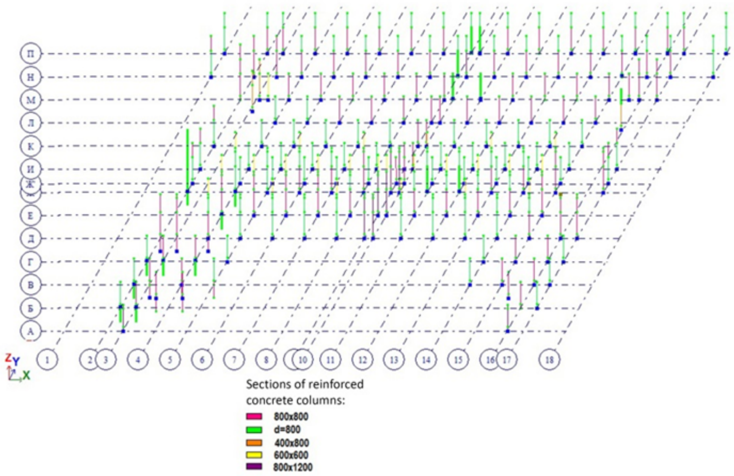

Figure 8. Arrangement of reinforced concrete columns.

10 variants of possible progressive collapse of structures in the most unfavorable places were analyzed. For all options, the incremental design load on the structure was set step-by-step (the total number of steps is at least 20), evenly and simultaneously for all load groups [3, 16-20]. Figure 9 shows the pattern of displacements for one of the possible destruction schemes (part of the reinforced concrete column in the axes I-4 at level 0.400m has been removed).

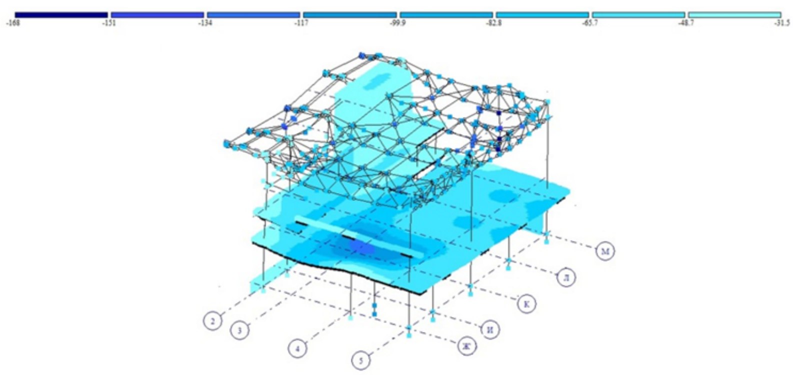

Figure 9. Removed reinforced concrete columns in axes I-4 at level 0.400 m.

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3. Conclusions

The Calculations showed that in the places of removal of the main support elements (columns, pylons), there are significant local deformations (sagging) of the bearing structural elements, including the partial destruction of some secondary elements. However, in all the considered variants the progressive collapse of the main load-bearing structures of the building does not occur, the building retains its overall integrity and stability when the full design loading is achieved.

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